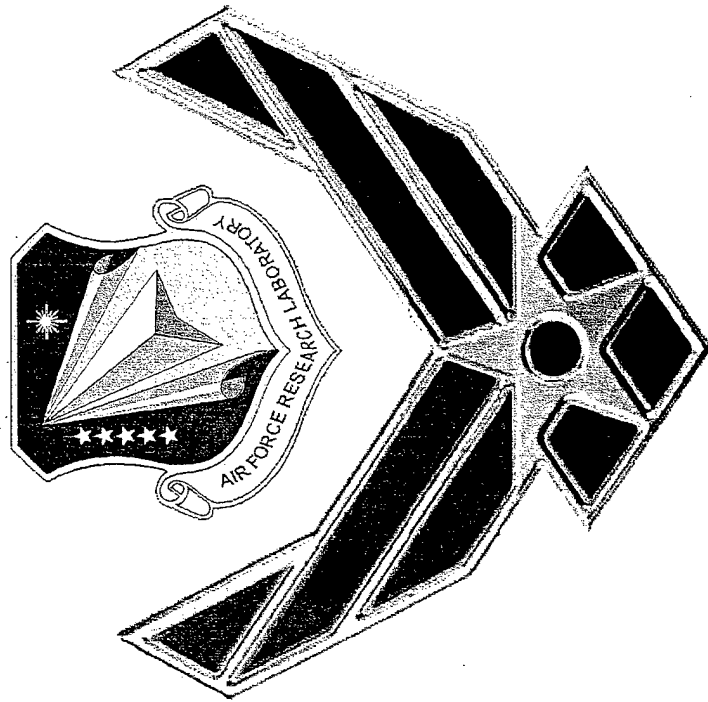


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DATA



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That's what it's all about ---

DATA

- Data
 - Evaluation
 - Decision

Objective

- **Data Validity**
- **Data Accuracy**
- **Data Reliability**
- **Summarize results**

FIRST QUESTION

Data Validity: Is the Data Real ?

- Sensor capability
 - Sensor installation
 - Data system capability
-
- Do the homework; know expected data range, frequency, and acceptable error
 - Need to address OSP environment; thermal cycling, radiation

SENSOR CAPABILITY

- **Measurement range**
- **Frequency response**
- **Thermal sensitivity/stability**
- **Zero balance stability**
- **Vibration sensitivity/stability**

SENSOR INSTALLATION



- **Connectivity**

- Heat
- Tubing

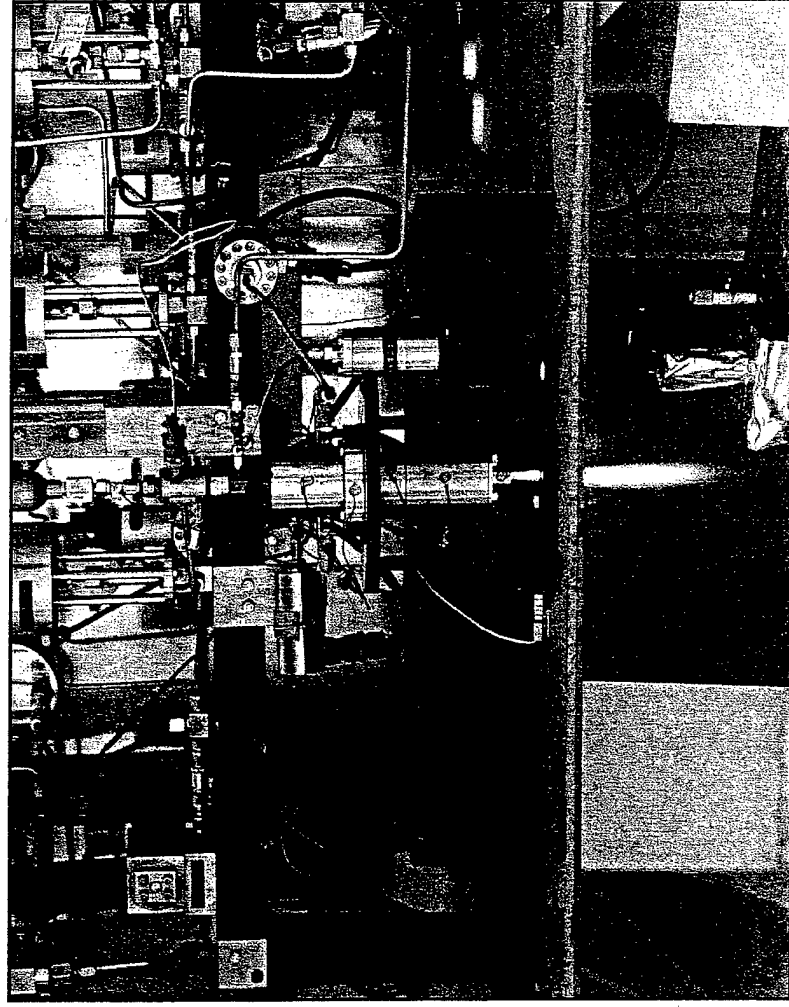
- **Orientation**

- alignment

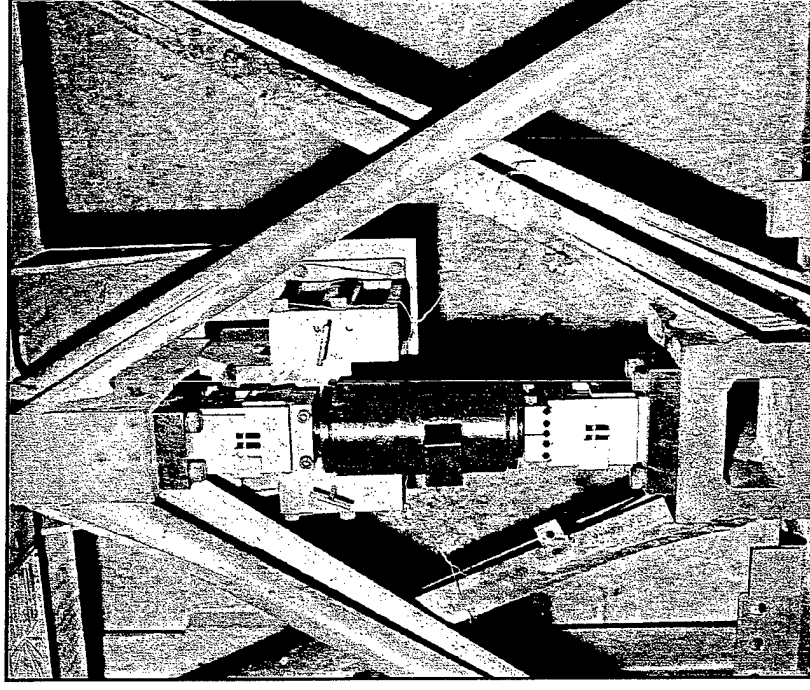
- **Excitation**

- mV/V

SENSOR INSTALLATION



TRANSDUCERS



LOAD CELLS

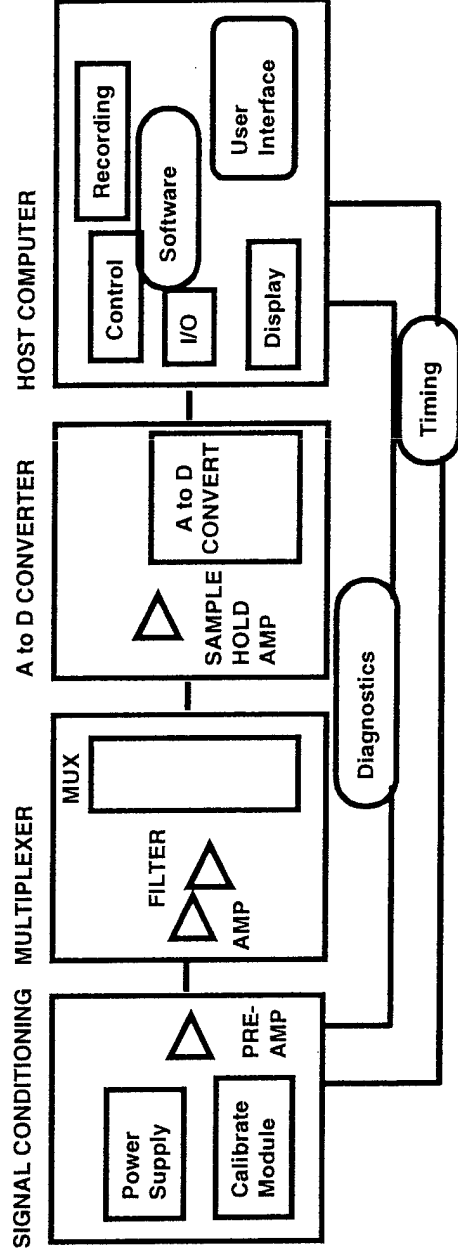
DATA SYSTEM SETUP

- Range
 - Gain/resolution
- Filter
 - Cutoff frequency
- Sample rate
 - Alias

DATA SYSTEM

- **System Modules**
 - Signal Conditioning
 - Multiplexer
 - Analog to Digital
 - Computer
- **Module Functions**
 - Number of Channels
 - Throughput
 - Data Manipulation
 - Precision
 - Resolution Accuracy

General Data Acquisition System Block Diagram

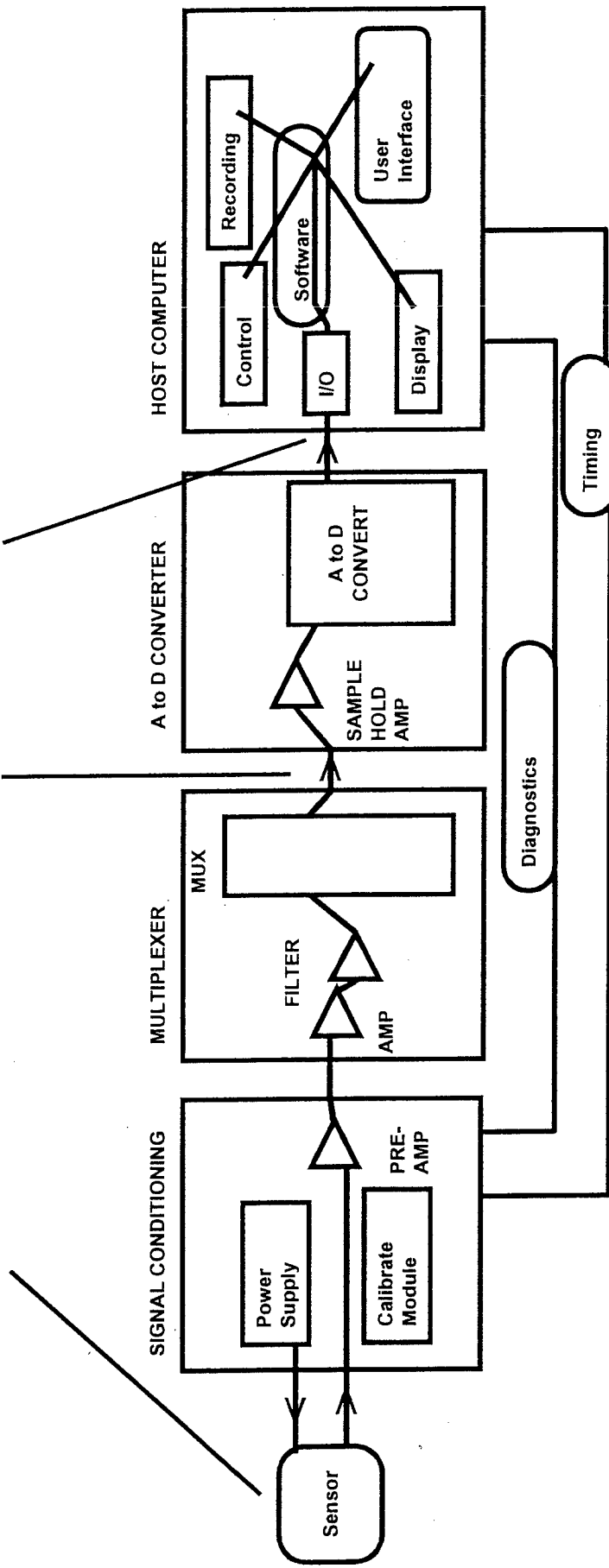


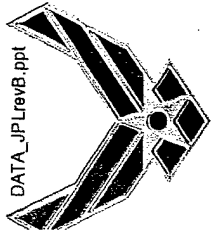
System Capabilities

- Amplification / Attenuation / Resolution
- Signal Sampling / Frequency Response / Anti-Alias
- Aggregate Sampling Rate

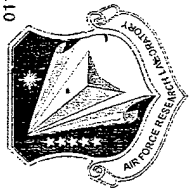
DATA FLOW

SENSOR INFORMATION DATA FLOW PATH





DATA VALIDITY



Data Validity: You can know the data is real

- **Do the homework;**
 - **know the requirements**
 - **Know the capabilities**
- **Substantiate the data**
 - **Noise “non-data” can exist in the data envelope**

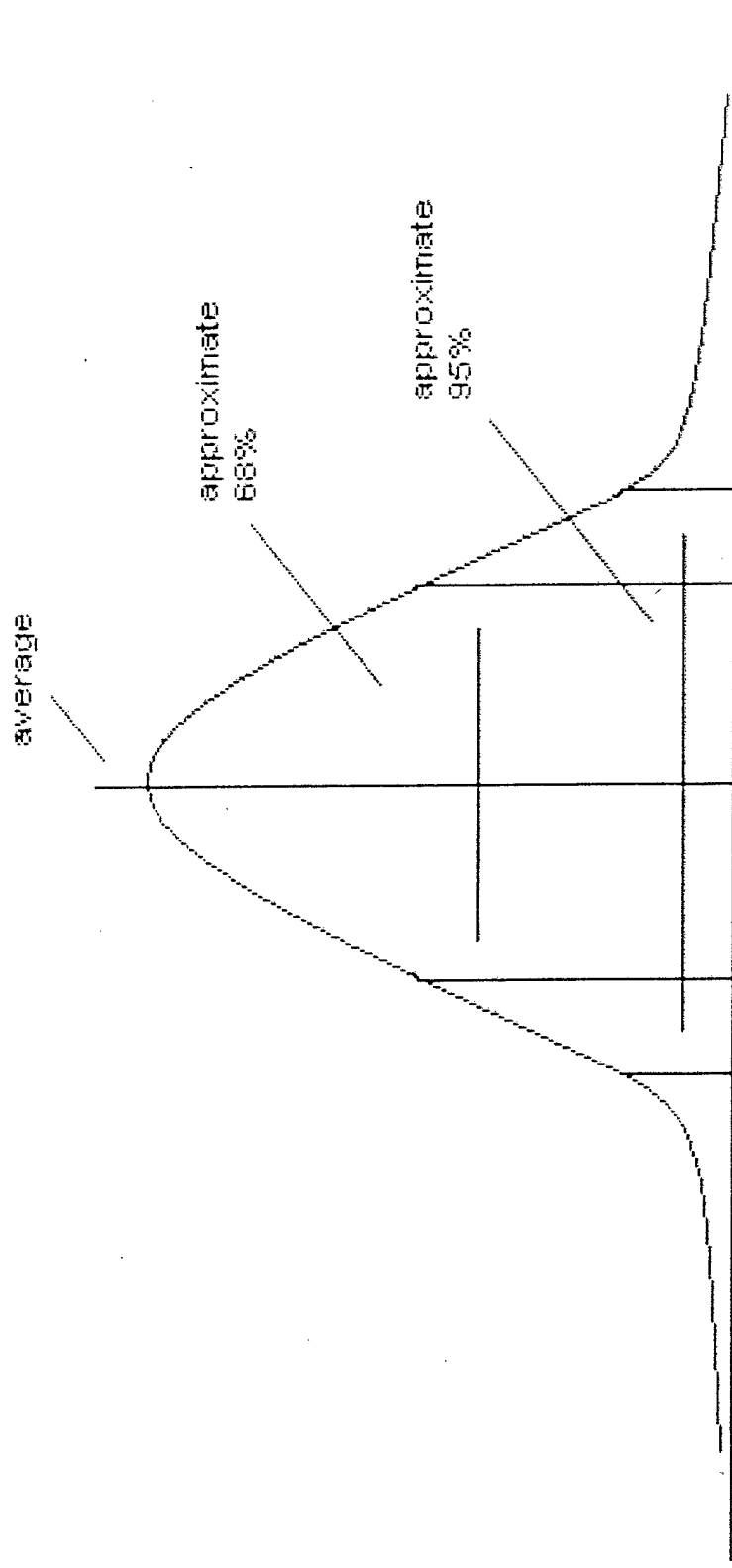
SECOND QUESTION

Data accuracy: What is the data error ?

- Do the homework; know expected data range, frequency, and acceptable error
- Does this “acceptable error” include 100%, or 95%, or 68% of the data
 - Error components
 - Sensor error +/-
 - Data system error +/-
 - Other error +/-

DATA DISTRIBUTION

Standard data distribution profile



DATA ERROR

- Example; if a 1500lb pressure sensor reads 700lb
- The customer will have defined “acceptable error” to be within some range such as;
 - +/- 0.9lb or 0.06%FS
 - +/- 6lb or 0.4%FS
 - +/-19lb or 1.2%FS

SENSOR ERROR

Sensor error may be calculated from manufacturer's specifications sheet

- Bias/offset/zero balance +/- 1.0%FS
- Linearity +/- 0.2%FS
- Hysteresis +/- 0.2%FS
- Repeatability +/- 0.2%FS
- Thermal shift zero +/- 0.005%FS
- Thermal shift span +/- 0.005%FS
- Shock/vibration sensitivity +/- 0.1%FS
- Algebraic sum of error = +/- 1.71%, or +/- 25.65LB
- Most conservative
- Root Sum Square (RSS)= +/- 1.063%, or +/- 15.945lb
- Less conservative
- Probability that not all error occurs at the same time

SENSOR CALIBRATION

Does this meet data error requirements?

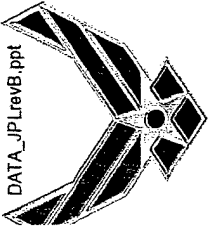
- data requirement; +/- 19lb
- estimated error (RSS approach);
 - +/- 1.063% (1500) = +/-15.945lb
- Good enough for Decisions?

- Quality/unknowns of specification sheet
 - All sensors / all data
- Large unknown and low confidence level

SENSOR CALIBRATION

Improve sensor error calculation with vendor's calibration.

- Nominally between .15% and .5% FS
- For the 1500lb example this equates to 2.25lb to 7.5lb
- Reduce the 1.06%
- Does this manufacturers "calibration error" include 100%, or 95%, or 68% of the data
- Vendors do not calibrate the same
 - Difficult to correlate sensor data



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DATA SYSTEM ERROR

Proved out the manufacturer's specifications, but error back to 1.0% FS

Need to quantify the entire data path error

- **Data system error**

- Linearity
- Zero balance
- Thermal shift
- Gain (span)
- Excitation voltage (value/stability)
- Common mode

- **Other error**

- Cabling; sensor to system (noise, thermal)
- Random; eletro-mechanical (frequency, capacitive induced spikes, etc); Tribo-electric (friction)
- ?? Barometric, temperature, sun

SYSTEM CALIBRATION

- **Use in-place system calibration**
 - Create a complete data path from sensor to data system
 - Using a known signal “standard”
 - Insert and record multiple steps form 0% through 100% of the sensor range
 - Captures all random error
 - Valid for given point in time
- **This curve fit will reduce entire data path error and increase confidence**

SYSTEM CALIBRATION

- Further reduction of error can be accomplished by using multiple calibrations
- Multiple “in-place” calibrations will capture the variability of all random error
 - Some error is variable
- This curve fit will further reduce entire data path error and increase confidence
 - Capture error variability associated with different points in time

DATA SYSTEM ERROR

Sensor calibration by itself

- Reduces error unknown and increases confidence
- Implies that all error is accounted for in the sensor
 - Variance is only in data

• Disregard of all other error may lead to problems

• Rule of thumb for error of the measurement;

sensor error	= approximately .25%
data system error	= approximately .1%
other error	= approximately .15%

- 2 times sensor nominal error from manufacturer's calibration for 1500lb example (.15% to .5%)=
 $2 \times .5\% = \pm 1.0\% \text{FS (conservative)}$

$$\pm 1.0\% (1500) = \pm 15.0\text{lb (conservative)}$$

UNCERTAINTY

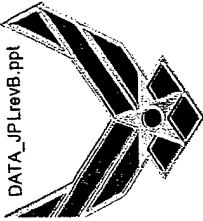
- Further reduction of error can be accomplished by using uncertainty calculation methods
- Apply standard uncertainty calculations
 - Account for the “sensor calibration” error and the “system calibration standard” error
- Will result in very well defined error band to support decision making
 - High confidence level

THIRD QUESTION

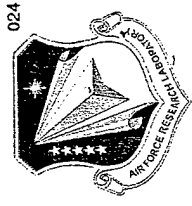
Data reliability: Can the data be trusted ?

- Installed sensors may/may not provide trusted data between calibrations
- Any/all of the three error sources may have changed
 - Intermittent signal
 - Zero shift (drift)
 - Data deviates from theoretical; higher, lower, or scattered

Data NEEDS to be verified between calibrations



DATA VERIFICATION



Data verification through VCAL

- Precision voltage insertion provides means to verify a signal “standard” through sensor path
 - Troubleshooting capability for
 - Intermittent signal
 - Zero shift (drift)
 - Data deviation from theoretical; higher, lower, or scattered
- Substantiate any deviation between sensors

Data CAN be verified between calibrations

- System interface cost (added components)

DATA VERIFICATION

Data verification through Smart Sensor

- Computer ship with diagnostic capability integrated into sensor
- Precision voltage/frequency diagnostic signal insertion provides means to verify a signal “standard” through sensor path
 - Troubleshooting capability for
 - Intermittent signal
 - Zero shift (drift)
 - Data deviation from theoretical; higher, lower, or scattered
- Substantiate any deviation between sensors

Data CAN be verified between calibrations

- System interface cost (sensor weight or added components)

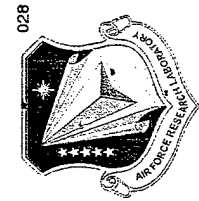
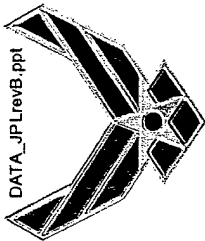
SUMMARY

- **Data Validity**
 - Do homework, know requirements and capabilities
- **Data Accuracy**
 - Calibration allows you to trade a large unknown error for a smaller known error and higher confidence level
- **Data Reliability**
 - Data can be verified

EXAMPLE

Following example shows relationship of error reduction for a 200 lb sensor

- **Manufacturer's specifications**
 - Algebraic sum = 1.71% of 200lb = ± 3.42 lb
 - RSS = 1.06% of 200lb = ± 2.12 lb
 - Only sensor error considered
- **Sensor calibration**
 - Eleven point calibration of 200lb = ± 0.19 lb
 - Only sensor error considered
- **System uncertainty**
 - Calibration standard error plus sensor calibration error plus 1500 point system calibration of 200lb = ± 0.21 lb
 - All error



EXAMPLE SPECIFICATIONS

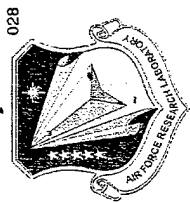
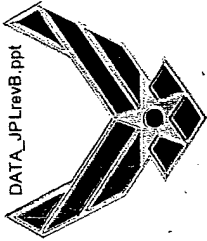
	error	error	sum of	error
	200.000	FS	squared	squares
Linearity	0.2000	0.040000	1.130050	0.0106304
Hysteresis	0.2000	0.040000		2.1260762
Repeatability	0.2000	0.040000		
Thermal zero stability	0.0050	0.000025		
Thermal span stability	0.0050	0.000025		
Shock stability	0.1000	0.010000		
Zero balance	1.0000	1.000000		

Following Pages

only presented as

back up

D.



EXAMPLE SPECIFICATIONS

	error	error	sum of	error
	200.000	FS	squared	squares
Linearity	0.2000	0.040000	1.130050	0.0106304
Hysteresis	0.2000	0.040000		2.1260762
Repeatability	0.2000	0.040000		
Thermal zero stability	0.0050	0.000025		
Thermal span stability	0.0050	0.000025		
Shock stability	0.1000	0.010000		
Zero balance	1.0000	1.000000		

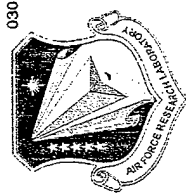
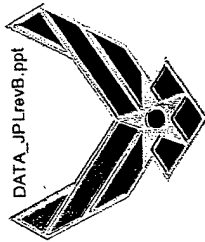


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EXAMPLE CALIBRATION

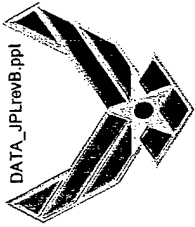
S.E.E. T95

MV	Observed	Predicted	Residual	N-K; K=2				sum of residuals squared	sum of residuals squared / N-k	sum of residuals squared / N-k	Sqr root N-1	t95 * SEE / sq root N-k
				sum of residuals squared	PSIG	sum of residuals squared	PSIG	sum of residuals squared	PSIG	for 6		
6	PSIG,Y	PSIG, Y1	PSIG, Y-Y1									
-0.006	0	0.033171	-0.033171	0.033171	0.350937	0.12316	4	0.03079	0.17547	2.447	2.23607	0.192021
39.970	40	39.979924	0.020076	0.020076								
79.970	80	79.950660	0.049340	0.049340								
119.970	120	119.921395	0.078605	0.078605								
160.090	160	160.012043	-0.012043	0.012043								
200.113	200	200.005762	-0.005762	0.005762								
160.140	160	160.062006	-0.062006	0.062006								
120.070	120	120.021322	-0.021322	0.021322								
80.012	80	79.992629	0.007371	0.007371								
39.970	40	39.979924	0.020076	0.020076								
0.002	0	0.041165	-0.041165	0.041165								



EXAMPLE UNCERTAINTY

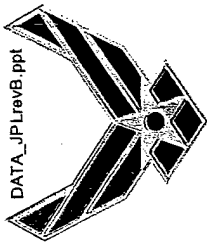
	All S x squared	total all N-1s	percent step	total all Sx * N-1
Systematic value sensor calibration				
Br=systematic/2=	0.19202 psig	2626		12141.93654
Bra^2=	0.09601 psig		0	311.2366356
Systematic value data calibrator	0.00922 psig		20	194.9793322
Brb^2=	2.5E-05 psig		40	1204.381498
Sx pooled = {sum [(vi)(Sxi^2)]/vi}^1/2			60	3179.505046
Sx= pooled	2.1502879		80	5310.86765
Sxbar = Sx / sqrtN = Sr			100	1940.966381
Sr = Sxbar=	0.0419613			
Sr^2=	0.00176 psig			
U95=+/-t95[sum (((Bra^2)+(Brb^2)+(Sr^2))1/2)]=	0.2098 psig			
Bandwidth=2xU95=	0.4196 psig			



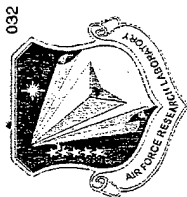
UNCERTAINTY

$$\bullet U_{95} = \pm t_{95} \sqrt{(B_r/t)^2 + (S_r^2)}$$

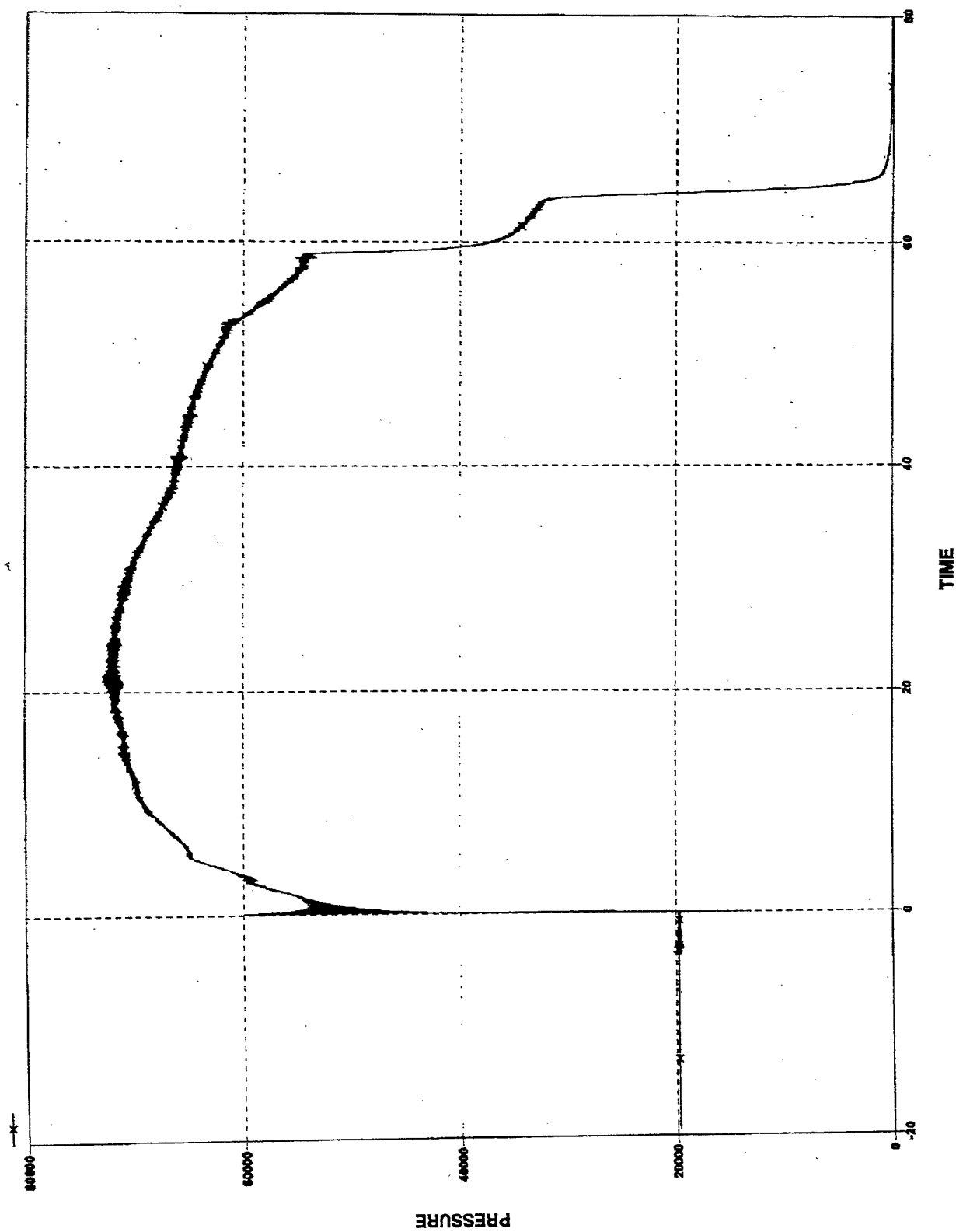
- t_{95} (Student's t); statistical value table for 95% confidence
 - Where v (number of samples minus 1) is greater than or equal to 30
- t ; statistical value where B_r is not a 95% confidence number
 - $t = 2$ when v is greater than or equal to 30
- B_r (systematic error)
 - Known signal standard
 - Sensor calibration/curve fit
- S_r (random)
 - Current multiple data steps recorded through the sensor



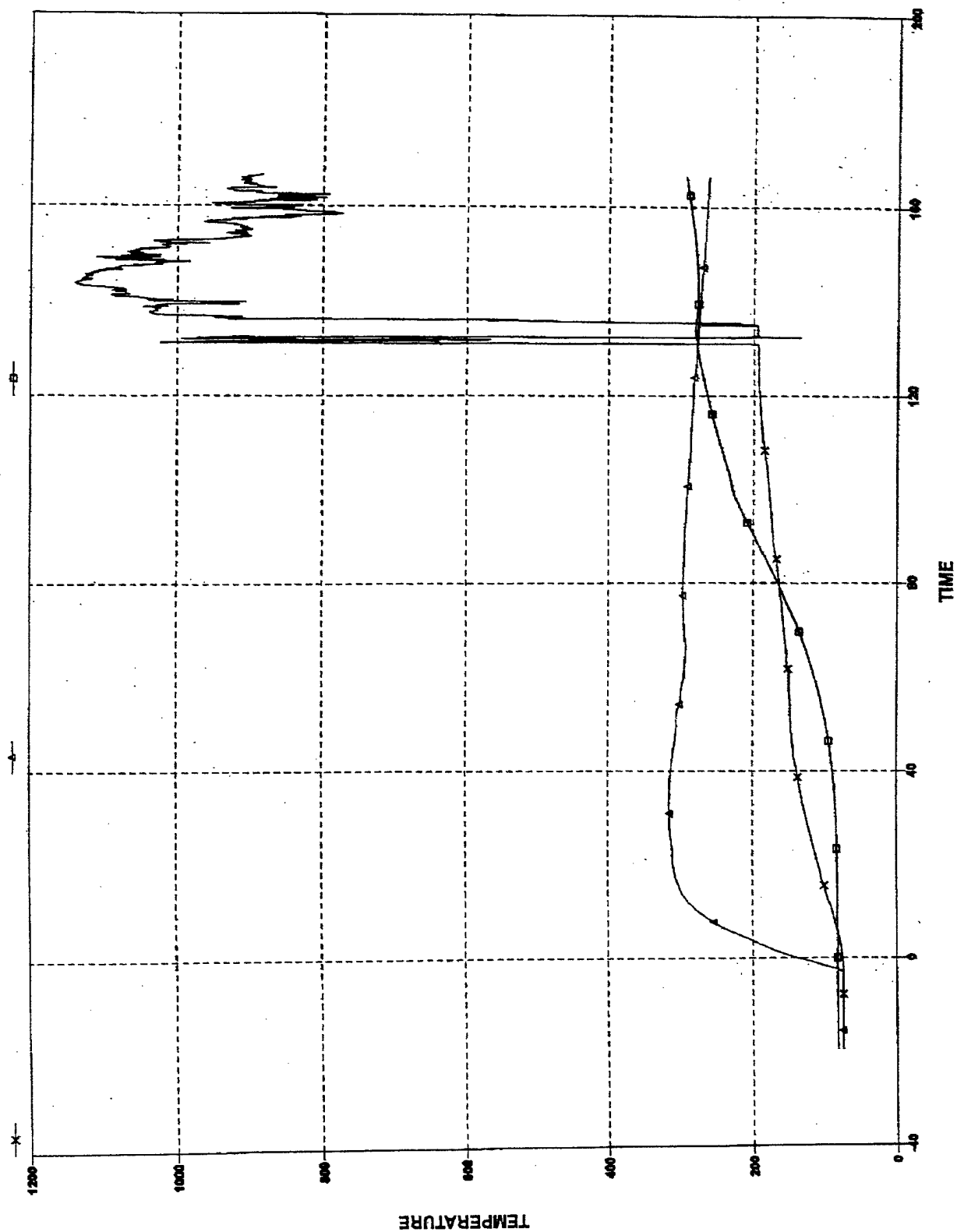
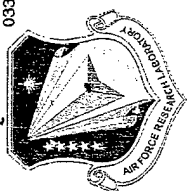
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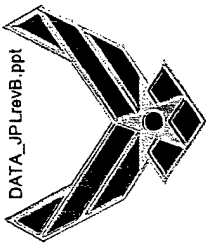


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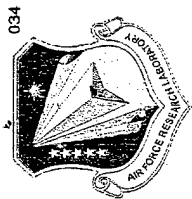


TIME

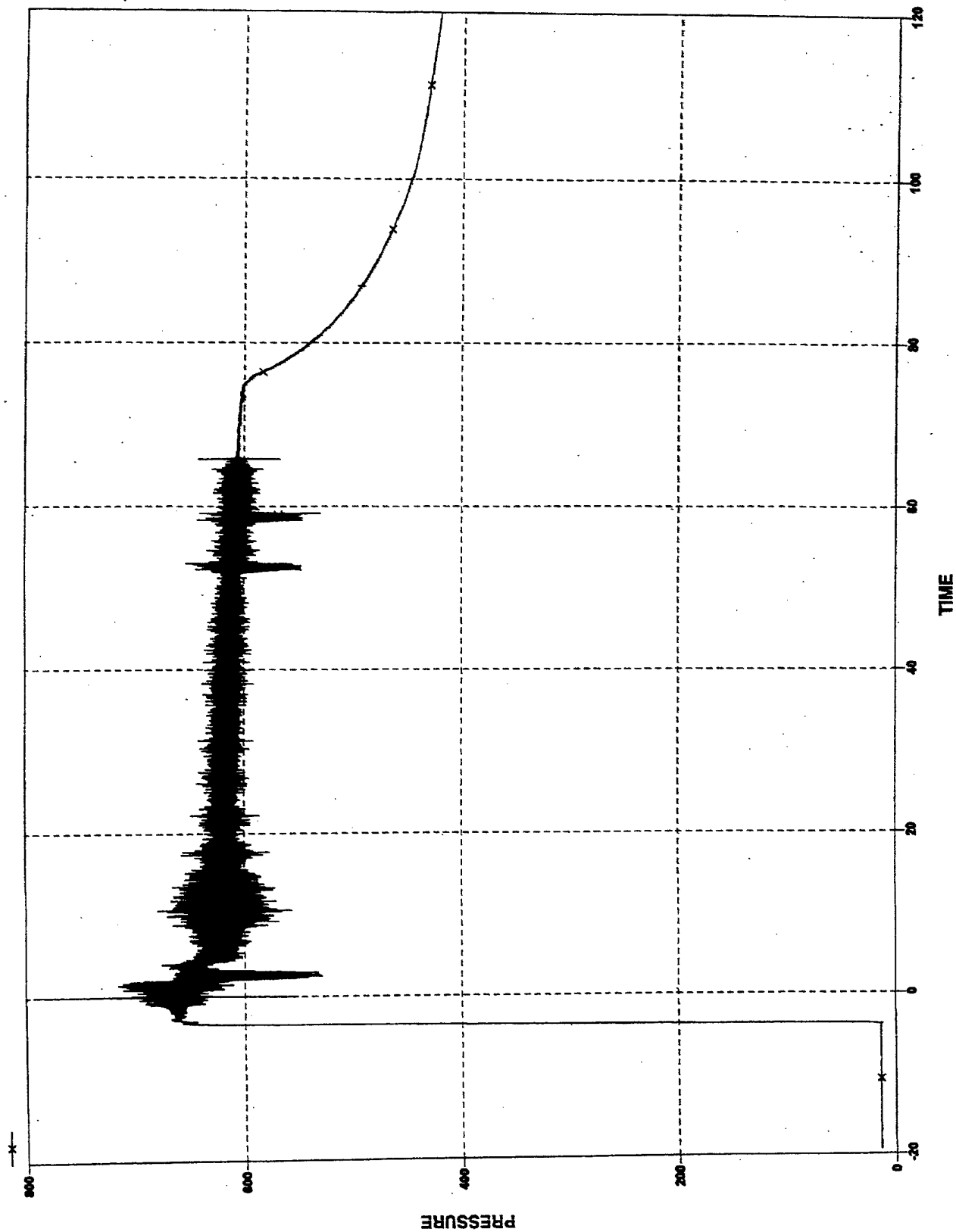


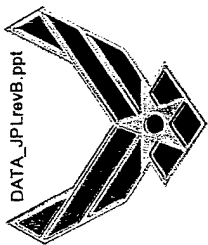


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034

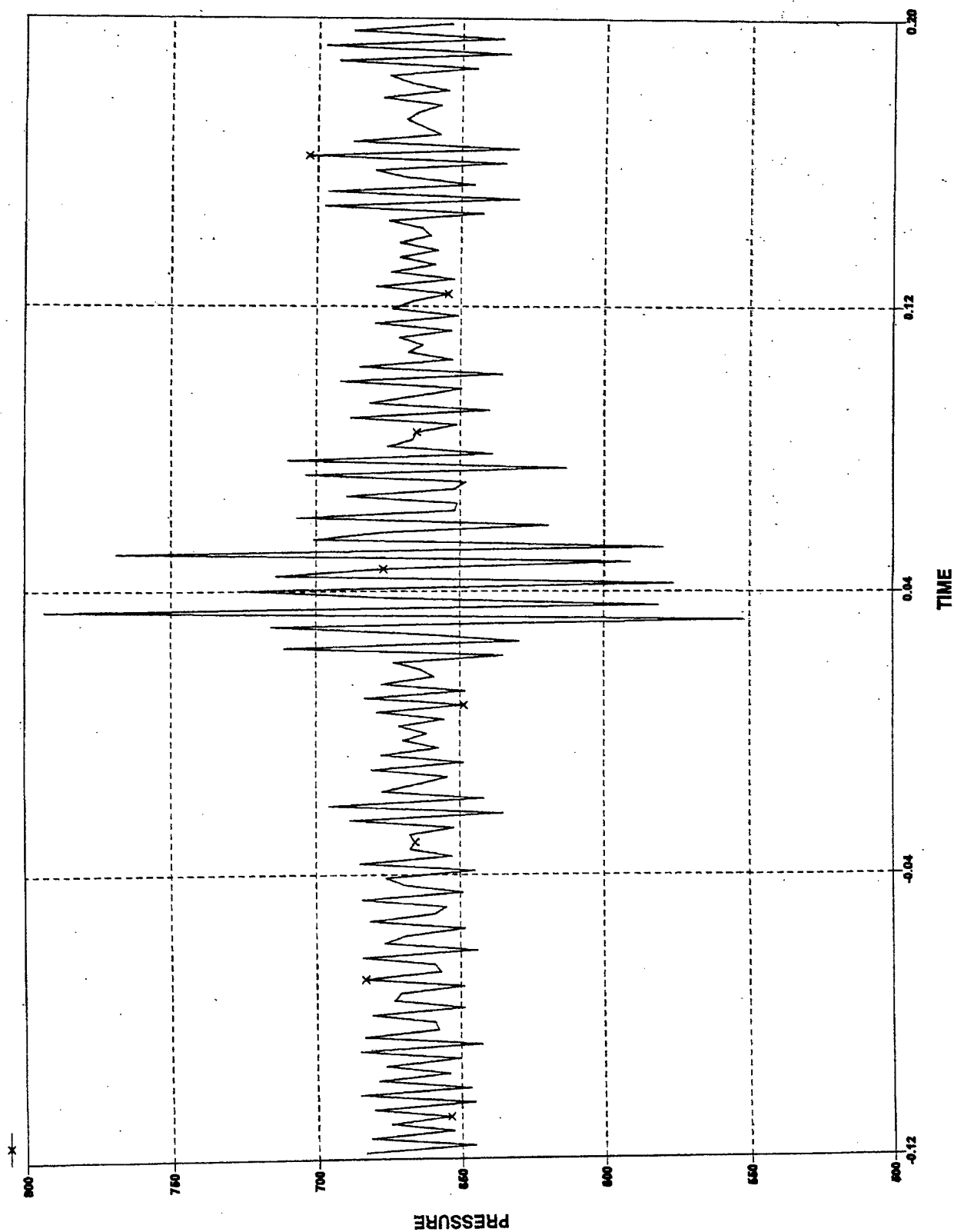


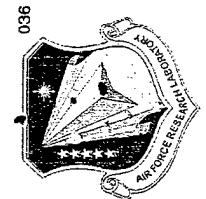
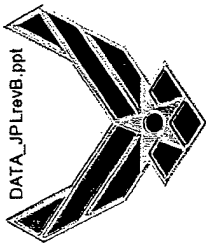


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